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High altitude platform stations as a component of non-terrestrial heterogeneous networks 4G/5G

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Abstract. One of the ways to solve the problem of creating a modern telecommunications structure in hard-to-reach areas of the Arctic, Asia, Latin America and a number of other territories is the introduction of communication networks of a new type of non-terrestrial networks (NTN), using not only satellite communication networks (SCN), but also various aerial systems. This article discusses the use of high altitude platform stations (HAPS) as a part of the architecture of NTN networks, which are capable of providing users with a wide range of communication services even in the absence of modern terrestrial telecommunications infrastructure. The options of NTN architecture using HAPS is described, in which they can perform the functions of repeaters or cellular base stations. The calculation of the energy characteristics of various radio links that are a part of a communication network based on HAPS is given. The example of the Arctic shows the feasibility of the proposed solution of using HAPS as a part of NTN and its high efficiency.

Keywords: 3rd Generation Partnership Project (3GPP); 4G/5G; cellular base station; communications satellite (CS); heterogeneous networks; high altitude platform station (HAPS); non-terrestrial networks (NTN); satellite communication networks (SCN)

1. Introduction

Currently, the provision of the full range of communication services, including personal mobile communications, in a number of regions, even very attractive ones for the economy, is extremely limited due to the lack of a modern telecommunications structure in this territory. Such territories include the Arctic zone (Bogachev *et al.* 2018, Delaunay and Landriault 2020, Saunavaara *et al.* 2021), providing communications in mountainous and inaccessible areas of Asia and Latin America, communication with sea and river vessels, airplanes, railway transport, etc. In most cases, a limited range of communications services can be provided using SCN based on geostationary (GEO) satellites, such as Inmarsat or low-orbit Starlink or Globalstar (mobile telephone and low-speed data) and Iridium (mobile telephony and data transmission up to 384 kbit/s) systems. But, for example, Starlink provides telecommunications services in the Arctic Council states only in a very limited area. To fully cover the Arctic in Starlink, it will be necessary to launch several hundred more CS with orbital inclinations above 70°. It is important to note that

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the cost of creating Starlink, according to various estimates, is 20-25 billion dollars, and the cost of ground terminals in this system is about 3 thousand dollars, which is a significant limitation on its successful commercial development.

An analysis of various options for building communication networks in the Arctic, the main technology in which is SCN, is presented in a number of publications (Anpilogov 2014, Prokhorov 2014, Prokhorov 2019, Plass *et al.* 2015, Sivaranjani and Shalini 2018, Chechin *et al.* 2022). However, the use of the most developed communication networks based on geostationary repeater satellites (GRS) in this region has a number of features and limitations in terms of service area (usually no higher than 70°), low energy potential of radio links due to the long length of the radio signal path in the atmosphere and small antenna elevation angles (1°-7°), reduced quality factor of ground terminals by 1-2 dB due to the high increased noise temperature of the Earth, the impossibility of using higher frequency ranges Ku and Ka due to significant attenuation of signal energy. For example, in the C and Ku ranges for a terminal located at 80° N at elevation angles of 1°, the increment in losses due to the atmosphere, rain and scintillations compared to an elevation angle of 45° is more than 10 dB and 14 dB, respectively. And the decrease in the energy potential of radio links is 15 dB and 19 dB, respectively (Anpilogov and Gritsenko 2021). All this leads to the fact that even if the ground terminal is in the service area of GPS, its antenna has a diameter of 1 m or more. In particular, to compensate for the indicated energy losses, the antenna diameter should be from 3 m to 5 m. Obviously, in such conditions, providing, for example, mobile satellite communications in northern latitudes is difficult or even impossible.

The main driver of the global telecommunications market is cellular networks (CN) 4G/5G. Therefore, SCN operators based on GEO, High Elliptical (HEO), Medium (MEO) and Low (LEO) Earth Orbit Satellites are interested in integrating with CN for many reasons. And one of the main directions for solving this problem is the creation of SCN using standard mobile devices used in 4G networks (in the future-in 5G networks) and in LPWAN networks for IoT services. Such solutions are designated Direct-to-Device (D2D) (Jones and Allison 2023), representatives of which are the projects “AST Mobile”, “Lynk Global” and “Starlink G2”.

On the other hand, CN also faced the problem of increasing the capacity of radio links between base stations and subscribers. To increase it, new frequency bands are required, as well as ensuring an almost global service area to provide modern services. Therefore, cellular operators are also interested in integrating with SCN.

One way to solve this problem is to create heterogeneous communication networks using not only SCN, but also various aerial systems (Ahmadinejad and Falahati 2021). In the scientific and technical literature, such networks are called NTN. According to the definition of 3GPP (Bacco *et al.* 2019, Rinaldi *et al.* 2020, Lin *et al.* 2021), NTN is a telecommunications network in which SCN (GEO, MEO and LEO), unmanned aircraft systems (UAS) and vehicles (UAV) and HAPS function as either a relay node or a base station gNB of 5G network.

The main distinguishing feature of NTN is its ability to provide sufficiently large service areas in regions where there is no modern terrestrial telecommunications infrastructure and/or its creation is extremely expensive. The generalized structure of NTN is shown in Fig. 1.

In NTN, subscribers interact simultaneously with LTE and 5G base station, i.e., operate in “dual-connectivity” mode. In 5G networks, there are two types of radio base station nodes: gNB and ng-eNB (Angri *et al.* 2021, Rinaldi *et al.* 2021). Both of these nodes allow a regular smartphone to connect to 5G Core Network. gNB base station allows 5G phones or devices to connect to 5G core network using 5G air interface, while ng-eNB allows 4G LTE devices to connect to 5G core network using 4G air interface.

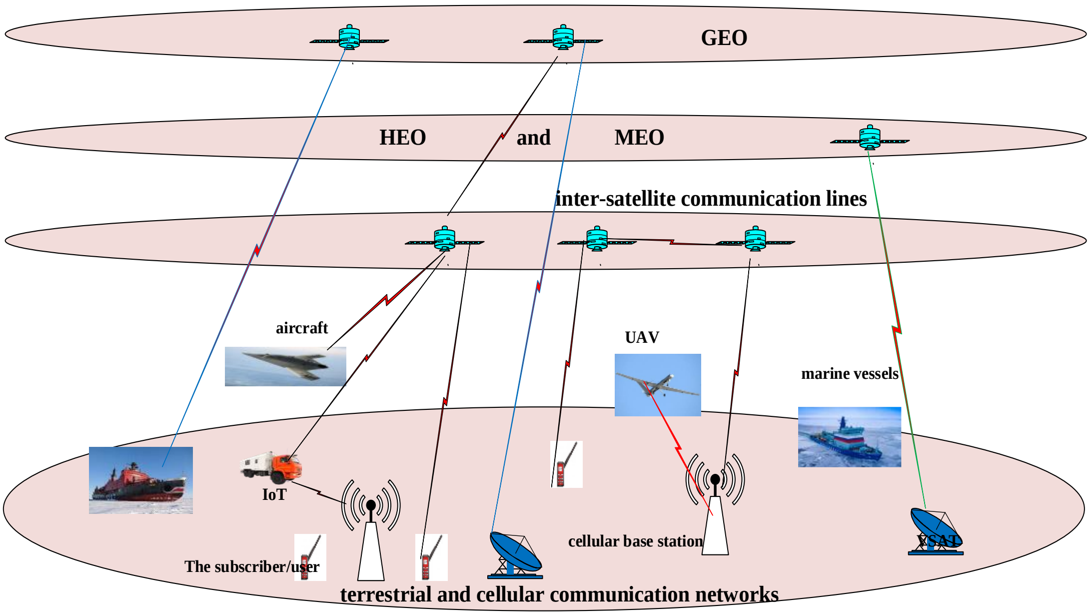


Fig. 1 General view of NTN

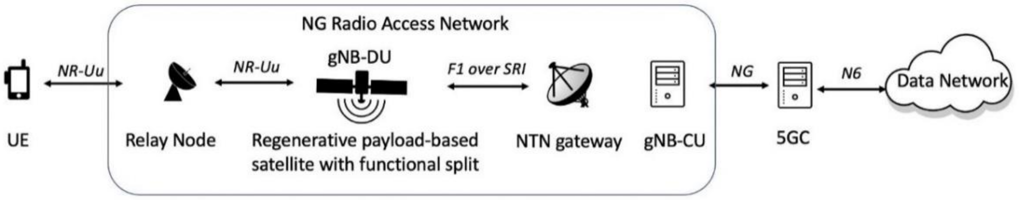
5G NTN deployment is planned using two technologies, namely:

- NR-NTN technology, which can be considered as an Enhanced Mobile Broadband (Popovski *et al.* 2018, Mamane *et al.* 2022), providing connection to subscribers based on CS,
- IoT-NTN technology, which will be an extension of IoT technologies such as NB-IoT, LTE-M or 5G RedCap (also known as 5G NR-Light) in satellite connectivity scenarios (Diaz Zayas *et al.* 2020, Prasad *et al.* 2023).

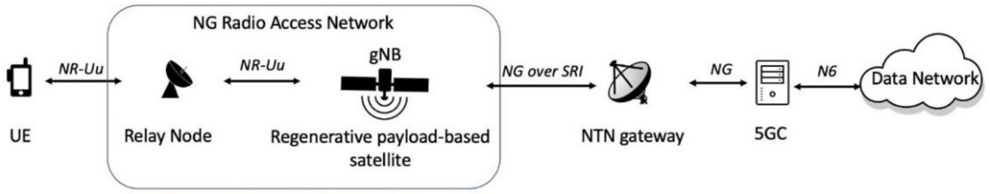
A feature of the Arctic is that the population is distributed unevenly and is concentrated within 100 km from large settlements. That is, in the Arctic it is not relevant to create a continuous service zone and spend billions of dollars on it, which are necessary for the creation of satellite systems, but it is relevant to create several dozen small service zones. But it is precisely such service zones that can be created quite easily by HAPS at an altitude of approximately 7 km. This article, which is a further development of the work (Chechin *et al.* 2022), specifies the concept of 3GPP and has three goals:

- scientific: to prove that the area of effective application of high-altitude HAPS platforms is precisely the Arctic region and that such construction of 3GPP NTN networks not only significantly increases the efficiency of LEO communication systems, but also enables subscribers to use personal mobile satellite communication services in the Arctic even using GEO, EEO and MEO satellite systems,
- technical: to prove that the use of high-altitude HAPS makes it possible to achieve the full range of modern communication services,
- practical: to prove that the use of high-altitude HAPS as part of 3GPP NTN network architecture in the Arctic significantly increases the economic efficiency of satellite systems.

2. Theoretical basis



(a) first architecture option



(b) second architecture option

Fig. 2 NTN architecture using relay satellites with on-board signal processing

The Next Generation Radio Access Network (NG-RAN) will add new interfaces and protocols to support traditional and new services (Ahmadi 2019, Launay 2021, Rinaldi *et al.* 2021). Two CS-based NG-RAN architectures are possible: signal relay without on-board processing and using a scheme with on-board signal processing. In the latter case, NTN platform can implement partial or full functionality of gNB base stations of 5th generation mobile network, depending on whether the functional separation of gNB extends to the central and distributed units.

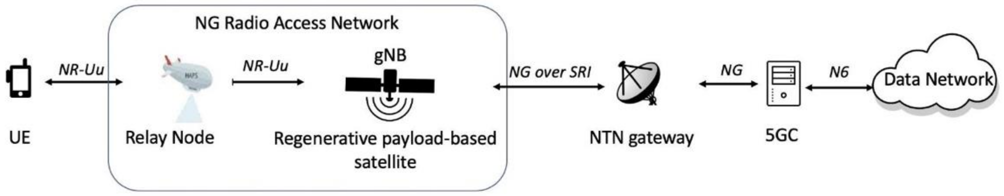
When using CS without on-board processing, NTN platform relays NR signal from NTN gateway to NTN terminal and vice versa. The satellite radio interface (SRI) on the feeder line is the same as the radio interface on the subscriber line (i.e., NR-Uu). NTN gateway can forward the NR signal of NR-Uu interface to gNB. One or more CS without on-board processing may be associated with the same ground gNB.

When using CS with on-board processing, NTN platform has built-in processing capabilities to generate/receive NR signal to (or from NTN terminal). NR-Uu interface is located in the subscriber channel between NTN terminal and NTN platform. The air interface between NTN platform and 5G core network (5GC) is NG, which communicates through SRI interface between NTN platform and NTN-gateway.

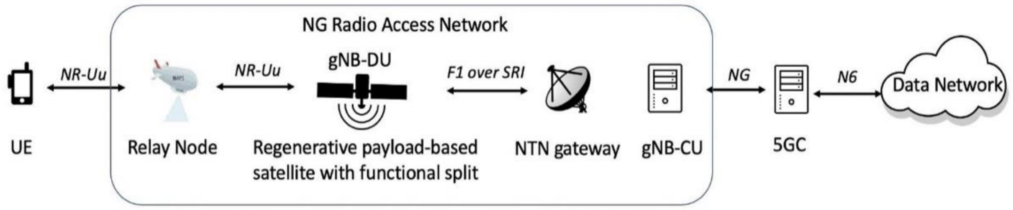
As follows from the description of NG-RAN architecture, gNB consists of a central gNB unit (gNB-CU) and one or more gNB distributed units (gNB-DUs) (Bertenyi 2018). In this case, it is also possible to use CS with or without on-board signal processing. Fig. 2(a) and (b) show two network architecture options when using CS with on-board signal processing, which in this case are full-fledged gNB nodes.

The main role in NTN projects is given to SCN, in particular low-orbit ones (Chechin 2022, Prasolov *et al.*2022). But to solve this problem it is necessary to create new types of ground terminals.

In the absence of satellite infrastructure and the concentration of users within small areas, which is typical, for example, for most areas of the Arctic, it is rational to place gNB node on HAPS (Widiawan and Tafazolli 2007, Bekkadal 2014, Mozaffari *et al.* 2017, Zhou *et al.* 2020, Chechin *et al.* 2022, Becvar *et al.* 2022). In this case, the architecture shown in Fig. 2 is transformed into the architecture shown in Fig. 3.



(a) first architecture option



(b) second architecture option

Fig. 3 NTN architecture using HAPS

This option for locating a node for small areas has significant advantages over SCN in terms of information transmission delay and in the ability to use a regular 4G smartphone as a ground user terminal. It is also important that even if the region is served by a low-orbit SCN, then in case of its overload, it is rational to route a part of its network traffic through the ground network, using gNB node located on HAPS as a gateway to the ground network. Moreover, when placing a node on HAPS, we will receive a gain in network throughput due to the fact that we reduce the length of radio links “terminal-gNB” by approximately 100-200 times compared to the length of the radio link through a low-orbit SCN, which provides a gain in energy approximately from 20 dB to 30 dB. And finally, in Arctic regions where the use of GEO and MEO SCN is problematic to provide personal mobile communication, HAPS can ensure the integration of cellular networks with SCN, serving as an intermediate hub for traffic from terrestrial subscribers.

An example of NTN network, which, along with SCN, uses HAPS, in relation to the territory of the Russian part of the Arctic, is presented in Fig. 4.

3. Materials and methods

As follows from Fig. 4, the proposed communication network integrates several terrestrial gateways with access to the backbone fiber-optic communication lines (FOCL) of telecom operators, CCS and (in some cases) SCN with additional intermediate communication nodes based on HAPS. HAPS, which house relay radio systems, are located at altitudes from 1-7 km (the boundary of the troposphere and stratosphere in the Arctic) to (in some cases) 20-22 km. Subscribers of the combined communication network use standard cell phones/smartphones as terminals.

The diameter of the service area of one HAPS depending on the height (h) of its placement and the working elevation angle (α) can be estimated based on the approximate ratio $D \approx 2h/tg(\alpha)$ (Ilchenko and Kravchuk 2010). Table 1 shows the D values for HAPS deployment altitudes of 5, 7 and 20 km. It should be noted that without modification of LTE protocol, the slant range of radio

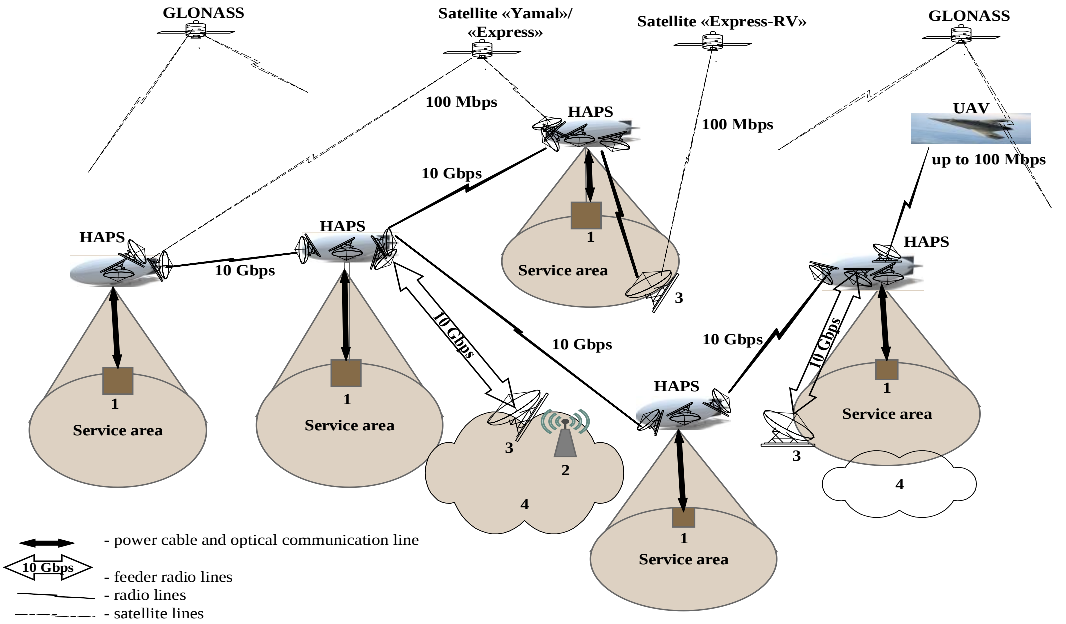


Fig. 4 General view of NTN network using HAPS: 1-Ground unit HAPS, 2-Central station of the mobile operator, 3-Gateway, 4-Terrestrial and CN

Table 1 Service area parameters depending on the HAPS placement height and working angle

α, deg	h=5 km/7 km			h=20 km		
	Diameter of the service area, km	Inclined range, km	Corner sector, deg	Diameter of the service area, km	Inclined range, km	Corner sector, deg
$\alpha=2^0$	227.8 / 400	114.1	174.0	657.4	329.7	170.0
$\alpha=3^0$	169.2 / 260	84.8	172.4	541.6	272.0	169.2
$\alpha=4^0$	133.0 / 200	66.7	170.8	454.6	227.3	168.0
$\alpha=6^0$	92.0 / 134	46.2	167.2	337.0	170.0	165.0
$\alpha=8^0$	69.8 / 100	35.2	163.4	264.2	133.8	161.6
$\alpha=10^0$	56.0 / 75	28.4	159.4	215.8	109.9	158.0
$\alpha=12^0$	46.6 / 70	23.8	155.6	181.6	93.1	154.4

links should not exceed approximately 45 km (this is due to the limitation on delays in 4G/5G networks). Table 1 also shows the values of the angular service sectors in which the beams of the HAPS multibeam antenna are formed. The radiation pattern (RP) widths of the antenna beams must be different, since the slant range increases significantly for beams deflected from nadir. The difference in signal energy attenuation between nadir and deflected beams is approximately 13 dB.

HAPS can also be placed at altitudes of about 20 km using stratospheric airships, as it is shown, for example, in (Anpilogov and Gritsenko 2021). But it should be taken into account that stratospheric platforms have significant technological risks and their implementation is associated with increased costs. As technologies for creating such platforms develop, they can take their rightful place in the proposed communication network architecture.

When using aerostats as HAPS at higher altitudes up to 7 km, it is possible to use standard technological solutions and platforms (Ilchenko and Kravchuk 2010), which have already proven themselves in practice as highly reliable UAS. Moreover, which is very important, HAPS at such an altitude are one or two orders of magnitude lower than at altitudes of 15-22 km. The existing experience in the production and operation of these carriers shows that on balloons with a volume of approximately 10-20 thousand m^3 it is possible to place a payload of up to 500-1000 kg (Chechin *et al.* 2022).

Obviously, to provide the same size service area as platforms at 20 km altitude, it will be necessary to place several HAPS at a lower altitude. But, in general, in the Arctic and other hard-to-reach places there is no need to create a continuous service area, because the population distribution in these regions is extremely uneven. In fact, the population in the Arctic is mostly concentrated within 100 km of major population centers. Those, in the Arctic, it is important to create a service area from a set of several dozen small service areas, but precisely such service areas can be created quite simply by HAPS at an altitude of up to approximately 7 km. When placing HAPS, for example, at an altitude of h=5 km, the energy gain compared to an altitude of 20 km will be $(20/5)^2=16$ times (12 dB).

The communication network, a general view of which is shown in Fig. 4, includes:

1. A network of HAPS located at an altitude of 1-7 km, which generally includes the following to solve various communication problems:
   - high-frequency equipment of cellular base stations for 4G cellular communications in LTE-1800 range (4G, LTE) 800, 900, 1800, 2100 and 2600 MHz, located on board,
   - transmitting and receiving equipment for communication lines with UAV,
   - receiving and transmitting equipment for communication lines with sea vessels of the Northern Sea Route,
   - equipment of feeder communication lines with ground gateway stations (Gateways) connected to the cellular operator network, with backbone FOCL of Russian telecom operators. These communication links can be implemented via FOCL (optical cable inside the tether, which also houses the power cable for powering HAPS) or via a platform-to-gateway radio link,
   - equipment from sensors of IoT systems using NB-IoT technology (typical version of 4G/5G CN) and LPWAN LoRa for servicing fast-moving unmanned systems,
   - on-board equipment for radio communication lines between HAPS platforms in Q/V range with a throughput of 10 Gbit/s,
   - equipment of the GLONASS system for controlling the platform and antennas of cross-platform and, in some cases, satellite communication lines,
   - in some cases: on-board equipment in the *Ku*-band (14/12 GHz) for organizing backup, and in some cases main, communication lines with GEO relay satellites “Yamal” and “Express”.
2. Several terrestrial transceiver base stations in individual cities of the Arctic, with access to the main FOCL of the main telecom operators of the Russian Federation with connection to the public switched telephone network, fixed network and CN, to Internet networks, departmental data networks and SCN, thereby performing the functions of network gateways for a communication network based on HAPS platforms.

The proposed architecture will make it possible to significantly expand the service area in northern latitudes when combining HAPS into a single network with 10 Gbit/s radio communication lines, and the separation of serviced regions can be up to several hundred km (Kamnev *et al.* 2019). It should be noted once again that this is a typical situation for the Arctic,

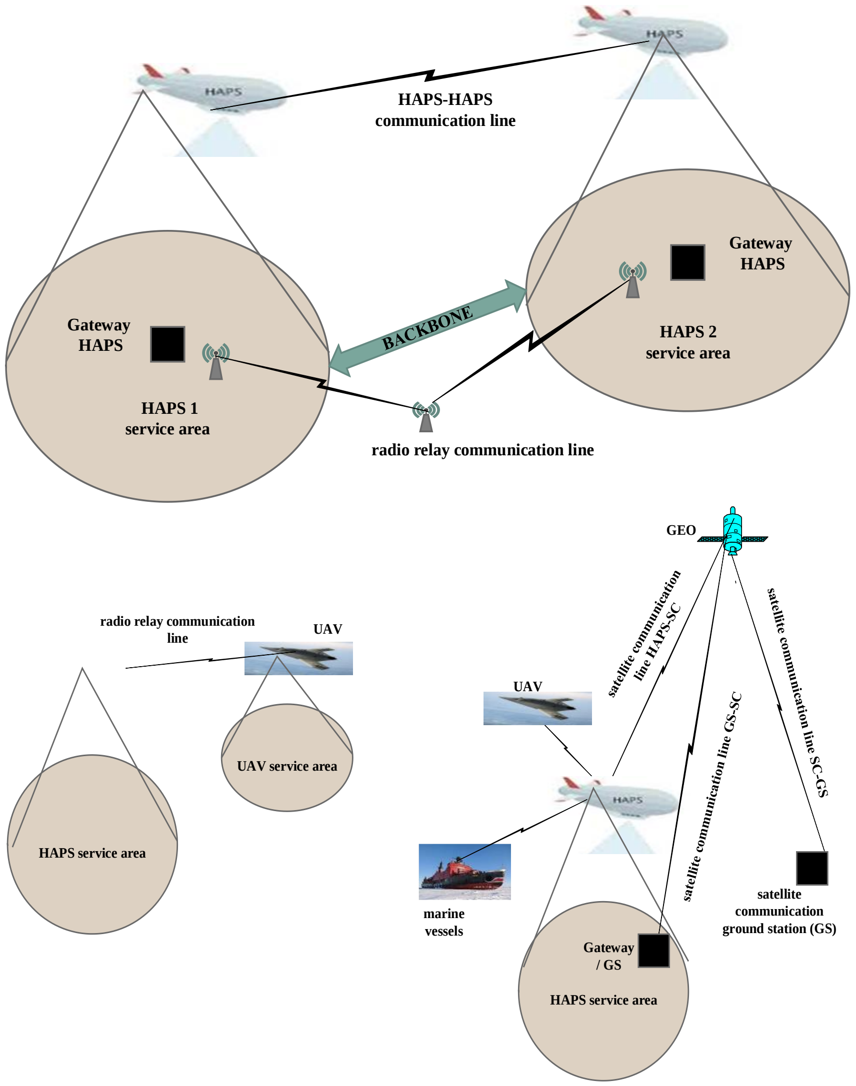


Fig. 5 Options for organizing communication lines via HAPS

which is characterized by a fairly large separation of settlements and the concentration of the population near them within 50-100 km.

The network architecture based on HAPS, options of which are presented in Fig. 5, provides for its rapid creation and flexible reconfiguration depending on the tasks, while users are provided with almost all communication services:

- personal mobile communication exactly in those places where it is in demand and using standard subscriber devices used in 4/5G networks,
- broadband Internet access for mobile and fixed subscribers,
- standard IoT services for monitoring and managing any production processes using standard subscriber devices of LPWAN LoRa networks,
- real-time IoT services for monitoring and managing unmanned systems.

4. Results

This section of the article is devoted to assessing the energy characteristics of various radio links that are a part of HAPS-based communication network. To do this, we will analyze the signal-to-noise ratio (SNR), which determines their throughput.

SNR at the input of the communication line receiver is determined by the well-known formula (1) (Kamnev *et al.* 2004)

$$SNR = P_t + G_t + G_r + \eta_t + \eta_r - L_t - L_r - L - L_{add} - P_n \text{ [dB]}, \tag{1}$$

where $P_n = 10 \lg (kT_nB_n/10^{-3})$ (dBm) is the total thermal noise power in dBm, where k is Boltzmann constant, $T_n = T_a + T_e$ is the equivalent noise temperature, T_a is the total losses in the antenna and noise (background) of the sky, $T_e = T_0\ (F_{sys}-1)$ is the receiver noise temperature ($T_0 = 290°K$, $F_{sys} = 10^{NF/10}$ is the receiver noise figure, and B_n is the noise bandwidth, which can be estimated as $(1.002 \div 1.57)B$, where B is the receiver bandwidth, P_t is the transmitter power (dBm), η_t and η_r are the efficiency of antenna-feeder transmitting and receiving paths, G_t and G_r are the gain factors of the transmitting and receiving antennas, respectively (dBi), L_t and L_r are the losses in antenna-feeder transmitting and receiving paths (dB), L is the loss of signal energy along the propagation path (dB), L_{add} are the additional losses in the communication line (dB).

The capacity of the communication line is determined as (2) (Kamnev *et al.* 2004)

$$C = \frac{P_s}{h_p^2\, kT} = \frac{P_t G_t S_r}{4\pi\, h_p^2\, r^2\, LkT} = \frac{\lambda^2 P_t G_t G_r}{16\pi^2 h_p^2 r^2 LkT}, \tag{2}$$

where: $h_p^2 - P_s$ is the threshold SNR, λ is the wavelength, r is the distance between receiver and transmitter (radio link length), S_r is the effective receiving antenna area.

4.1 Energy characteristics of inter-platform radio links "HAPS - HAPS"

The maximum range of "HAPS-HAPS" radio links is equal to (3) (Ilchenko *et al.* 2010)

$$D = (2R_e)^{1/2}(h_1^{1/2} + h_2^{1/2}), \tag{3}$$

where $R_e = 6371$ km is the average radius of the Earth, h_1 and h_2 are the altitudes of placement of adjacent HAPS, km.

We assume that HAPS are located at an altitude of $h_1 = h_2 = h = 5$ km. Then the maximum range of the radio link will be $D \approx 505$ km.

The maximum range of "HAPS-HAPS" radio links when platforms are placed at an altitude of 5 km will be about 500 km. Taking into account the instability of HAPS placement height of approximately +/-0.25 km and the minimum distance between HAPS equal to the maximum diameter of the service area, for example, 100 km, it is advisable to take the antenna beamwidth of at least 20. In this case, the antenna gain will be approximately 38 dBi. The result of assessing the energy characteristics of such a radio link at a frequency of 27 GHz (in this case, the equivalent antenna diameter is approximately 0.35 m) is given in Table 2. From preliminary calculations it follows that when using DVB-S2x standard and the accepted source data, single digital stream rates are achievable in the radio channel up to approximately 2 Gbit/s (achievable SKK 256APSK 2/3). To increase the speed to 10 Gbit/s, we should increase the transmitter power by 3 times or organize several radio links.

Table 2 Values of the energy characteristics of radio lines “HAPS-HAPS”

Parameter	HAPS 1	HAPS 2
Height of HAPS placement, km	5	5
Frequency of the radio line, GHz	27	27
Frequency band of the channel, GHz	1	1
Antenna gain, dBi	38	38
Transmitter power, W	10	10
Noise temperature of the receiving system, °K	1000	1000
SNR value, dB		
maximum	17.4	17.4
minimum	14.4	14.4

Table 3 Values of the energy characteristics of radio lines “HAPS-4G smartphone”

Parameter	HAPS	4G smartphone
Height of HAPS placement, km	5	0
The frequency of the radio line, MHz	1800	
Frequency band of the channel (beam), MHz	10	
Gain factor in the maximum deflected beam, dBi	14.4	-
Beam transmitter power, W	1	-
4G Smartphone antenna Gain, dBi	-	0
The noise temperature of the 4G smartphone receiver, °K	-	1200
SNR value, dB		
maximum	-	17.7
minimum	-	14.7

It should be noted that the total throughput of a network of several HAPS will be higher than the throughput of cross-platform radio communication links of 10 Gbit/s, because the network will include several interface points with geographically dispersed gateways of terrestrial core networks.

4.2 Energy characteristics of radio links “HAPS-4G smartphone-HAPS”

The results of the preliminary calculation are given for a radio link range of 100 km and an operating frequency of 1800 MHz. HAPS multibeam antenna forms a fan of beams, all beams are placed in an angular sector of approximately 172°, but the maximum gain should be achieved in the most deflected beams, which determines the maximum size of its aperture. It is assumed that the size of the transmitting antenna aperture will be no more than 0.5×0.5 m, with the outer beams having RP width of approximately 30°. The central beams have wider RP. The energy assessment for the “HAPS-4G smartphone” communication line shows that the maximum transmission speed will be approximately 45 Mbit/s (CQI index=10) and will not be lower than 39 Mbit/s (CQI index=9) and is shown in Table 3.

We also assume that HAPS receiving antenna system has dimensions similar to the transmitting one and is located at the maximum possible distance from it. The energy assessment of “4G smartphone-HAPS” radio links is given in Table 4. The maximum speed that will be achieved in

Table 4 Values of the energy characteristics of radio lines “4G smartphone-HAPS”

Parameter	4G smartphone	HAPS
Height of HAPS placement, km	0	5
The frequency of the radio line, MHz	1800	
Frequency band of the channel (beam), MHz	1.4	
Gain factor in the maximum deflected beam, dBi	-	14.4
Beam transmitter power, W	0.2	-
4G Smartphone antenna Gain, dBi	0	-
Noise temperature of the 4G smartphone receiver, °K	-	600
SNR value, dB		
maximum		17.7
minimum		14.7

deflected beams will be approximately 2 Mbit/s (CQI index=4). To increase the transmission speed, it is necessary to increase the aperture of the receiving antenna system.

4.3 Energy characteristics of radio links “HAPS-IoT device-HAPS”

We carry out the calculation in this case using LoRa technology (HAPS payload is a collection of typical LoRa base stations). The use of NB-IoT technology, which is a typical option in 4G/5G CN and provided when using smartphones, has a certain disadvantage, since it does not ensure the functioning of IoT devices placed on high-speed devices, for example, for monitoring UAV.

In this case, the antenna system placed on HAPS is a simple microstrip emitter: one transmitting emitter and four receiving emitters, forming four beams (each with RP of 85°) in order to increase the system capacity on the uplink. We consider the range of used frequencies 863-868 MHz, which is adopted in the Russian Federation for the license-free use of IoT subscriber devices. The diameter of HAPS service area is approximately 170 km, but if IoT device moves outside this area, then its service can be done, for example, by the promising satellite network “Marathon IoT”. We assume that the parameters of IoT subscriber devices are completely identical, and the reception and transmission channels have a time division. The number of channels that can be placed in one beam in 863-870 MHz band is approximately 35. Accordingly, up to 140 channels can be organized in receiving beams.

With the accepted initial data, the assessment of radio link energy is given in Tables 5 and 6. Calculations have shown that it is possible to apply the highest spectrum expansion factor SF=5 (Spreading Factor is the rate of change of frequency in a radio pulse with linear frequency modulation). In the specification LoRaWAN there are six types, from SF7 to SF12: the higher the SF value, the slower the data is transmitted, but the higher the probability of error recognition), which is necessary for monitoring and control of UAV. In total, on one frequency channel, support and control of up to 40 UAV can be provided (operation in Class C with continuous sending of packets of up to 200 bytes with a cyclic frequency of approximately 7 seconds) located simultaneously in the working area of HAPS network. At the same time, the number of IoT devices that do not require real-time operation can reach tens of thousands on the network. The data in Tables 5 and 6 show that it is possible to provide an energy reserve of up to 20 dB, which makes it possible to provide IoT device service in enclosed spaces.

Table 5 Values of the energy characteristics of radio lines “HAPS-IoT device”

Parameter	HAPS	IoT device
Height of HAPS placement, km	5	0
Frequency of the radio line, MHz	863	
Frequency band of the channel (beam), MHz	125	
Beam gain factor, dBi	0	-
Beam transmitter power, Вт	1	-
IoT Device Antenna Gain, dBi	-	0
Noise temperature of the receiving system IoT device, °K	-	1200
SNR value, dB		
maximum	-	12.5
minimum	-	9.5

Table 6 Values of the energy characteristics of radio lines “IoT device-HAPS”

Parameter	IoT device	HAPS
Height of HAPS placement, km	0	5
Frequency of the radio line, MHz	863	
Frequency band of the channel (beam), MHz	125	
Beam gain factor, dBi	-	6
Beam transmitter power, W	0.025	-
IoT Device Antenna Gain, dBi	0	-
Noise temperature of the receiving system, °K	-	600
SNR value, dB		
maximum	-	5.4
minimum	-	2.4

4.4 Energy characteristics of UAV-HAPS radio links

The target payload of UAV can be varied, up to the transmission of radar data when using large enough UAV. We assume in our calculations that the minimum mass of UAV is 3 kg. This condition imposes restrictions on the mass and consumption of radio link equipment in HAPS direction. We also assume that the flight altitude of UAV is no more than 500 m.

In this case, the frequency range of radio links can be adopted similar to that for the operation of a smartphone. Accordingly, UAV equipment should have parameters similar to a smartphone. Then the transmission speed of the target information will reach at least 45 Mbit/s. As it is shown in many publications, this transmission speed is sufficient to solve most problems. It should be noted that the data presented are valid for UAV flight speeds up to approximately 250 km/h (it must be said that this requires more detailed calculations, clarification and experimental confirmation). If the speed of UAV is significantly higher, then you should switch to 868 MHz frequency range and use LoRa technology. In this case, the transmission speed in communication lines will be no more than 10 kbit/s.

4.5 Energy characteristics of feeder lines

HAPS feeder lines (platform and gateway communication lines) can be implemented in several ways:

- using FOCL and connecting to the nearest communication center of the unified telecommunication network of Russia, including the use of a radio relay radio link (the communication center is located in another territorial area),
- using a radio feeder line in a radio range acceptable taking into account the frequency distribution table. For example, this can be implemented in the 20/30 GHz range in order to unify the solution with *Ka*-band VSAT (ability to operate in *Ka*-band is due to the fact that the Arctic of the Russian Federation belongs to climatic zones A and C).

The feeder line in the direction from the gateway to HAPS must provide a transmission speed sufficient to provide cellular and IoT network services with a given quality under given loads. In general, it is advisable to focus on a speed of no more than 10 Gbit/s. In the opposite direction, as experience in the functioning of cellular communication networks shows, the speed will be several times lower, no more than 2 Gbit/s.

It should be taken into account that on HAPS the size of the antennas should be minimized in order to reduce the load on the drive when mechanically pointing the antenna. An alternative solution is to use active electronically scanned array (AESA) with a minimum number of emitters. The Gateway antenna must be selected according to its aperture size to avoid electromagnetic compatibility (EMC) problems with other systems, including satellite ones.

5. Brief economic aspects

When placing a multiplexer and EEO, MEO or LEO satellite communications terminal (for example, Starlink communications network) on HAPS in addition to the base station, the high-altitude platform becomes a traffic concentrator from cellular subscribers to the network. At the same time, cellular subscribers receive all the services of the Starlink network on their regular smartphones.

Placing GEO systems terminal on HAPS opens up the opportunity for subscribers located at latitudes above 70° to use the communication services of satellite systems based on GRS using regular smartphones.

Thus, the use of HAPS as part of 3GPP NTN network architecture in the Arctic significantly increases the efficiency of satellite communication systems in terms of expanding the customer base and reducing the cost of communication services, since subscribers do not need to use satellite system terminals, the cost of which is more than an order of magnitude higher than the cost of a regular smartphone.

6. Discussion

The organization of communication nodes in NTN not only on low-orbit relay satellites, but also on HAPS significantly expands the possibilities for fast, economical and technically highly efficient integration of heterogeneous networks. The calculations of the energy characteristics of communication lines in such a network presented in the article fully confirm the possibility of providing a wide range of services and compare them favorably with services that can be provided using smartphones through low-orbit communication networks (currently this is only speech and SMS). The concept of using HAPS in NTN presented in this article expands and specifies the technical specifications of 3GPP Release 16-18 (Lin 2022).

It is obvious that for the practical implementation of the proposed communication network concept, it is necessary to solve a number of technical problems. As a development of the results obtained in the article, the authors believe that promising issues include the organization of information exchange in conditions of unstable HAPS retention, the selection of appropriate antenna systems and certain solutions for changing the timeouts of LTE protocol to ensure communication in subscriber lines over 45 km.

7. Conclusions

The last decade in telecommunications has been characterized by important technological advances and a significant increase in demand for new services. These developments have increased interest in NTN as a means of delivering advanced communications services by achieving global network coverage through the integration of satellite, cellular, airborne and terrestrial communications networks.

This article analyzes the use case for HAPS as a part of the architecture of 3GPP NTN networks, in which HAPS can serve as repeaters or cellular base stations. The main advantage of the proposed communication network is the use of standard smartphones as subscriber terminals and 4G/5G base stations as communication equipment. It is also important that it is also possible to use the wide range of equipment currently available from many vendors as channel-forming equipment for radio communication links with UAV and IoT sensors.

The network architecture proposed in the article fully complies with the concept of NTN 3GPP networks and expands not only its functionality, but also the range of services provided that require high throughput of communication channels. At the same time, HAPS, being an intermediate node-concentrator of traffic from terrestrial subscribers, significantly facilitates the integration of the terrestrial network with satellite networks. The calculations of the energy characteristics of radio links in the proposed version of NTN network fully confirm the possibility of providing a wide range of modern communication services.

It has been proven that the area of effective application of high-altitude HAPS platforms is precisely the Arctic region and that such construction of 3GPP NTN networks will not only significantly increase the technical and economic efficiency of LEO communication systems, but will also provide subscribers with the opportunity to use personal mobile satellite communication services in the Arctic even using GEO, EEO and MEO satellite systems, which is currently impossible to implement.

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